

Uncertainties of the Analyses of Altered Flows as discussed in FEIS

Gordon H. Reeves, PhD.
Susan Lubetkin, PhD.

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Summary

The analysis of the effect of flow alterations on the availability of fish habitat has a high degree of uncertainty associated with it. The ACOE was repeatedly asked to address the uncertainty of their results and conclusions, which is generally done in studies that depend heavily on models of complex situations. The FEIS acknowledges that “There is uncertainty associated with the magnitude of the impact of the mine on streamflow” in the affected streams (Appendix K4.24 – 25). However, results and conclusions about the effect of flow alterations are made with an unwarranted suggestion of a higher degree of precision and validity. And, there was no consideration or recognition was given to the high levels of uncertainty associated with every step in the analysis. In addition, the FEIS failed to adequately consider crucial portions of the aquatic environments (side-channels) and climate change, and limited consideration of effects of a given flow to single point (e.g., spawning habitat, juvenile habitat in the day) when there are additional potential effects later in time from the immediate effect. Recognizing and considering uncertainty associated with an analysis or study is critical when deciding on a course of action. Approving a permit for the proposed mine based on the results and conclusions in the FEIS is likely to result in large and irreparable harm to the fish populations in the affected streams and have potential ecological, economic, and social consequences to the affected streams and throughout the Bristol Bay area.

Assessment of The Flow Alteration Analysis

There were repeated suggestions by state and federal agencies and some interested parties to include and consider the uncertainties of the analysis of changes in flow to available fish habitat in the FEIS. The response was the production of RFI 147, RFI 149, and RFI 167 by the Applicant and their consultants and Appendix 4.16 in the FEIS. The latter acknowledged “There is uncertainty associated with the magnitude of the impact of the mine on streamflow in the NFK, SFK, and UTC.” (Appendix K4.16 -25), but then never considers the implications to the results for flow effects or how this affected the results of the PHABSIM analyses. Also, the FEIS states: “It is also worth noting that although the streamflow predictions are presented to one-tenth of a cfs, they are probably not that accurate.” (Appendix K4.16 - 25). It is further acknowledged that: “The EIS team does not understand the inner workings of the model (Added: flow) well enough to confirm that the values presented are all correct.” (Appendix K16 - 24) and that there are “some apparent anomalies” in the flow data “which might be attributable to typographic errors or errors in computations or assumptions” (Appendix K4.16 – 25). Examples are presented but then this appears to not be considered elsewhere in the FEIS.

The RFIs provided increasing levels of detail about how the modeling was done and more data, explain the details of components of PHABSIM, and continue to imply that the results have a very high degree of precision, as indicated by the lack of confidence intervals and the calculation of Weighted Usable Area (WUA) and rates of change in available habitat down to the level of the second decimal point. It was further suggested in RFI 047 that because PHABSIM has been used extensively in the past to determine the effects of flow alterations on fish that it was appropriate to use for determining the potential effects of the Pebble Mine. The support for this

contention were the citation of papers from industry organizations or interests, most which were published shortly after the development of PHABSIM and assessments were limited, and a more recent paper by Reiser and Hilgert (2018), consultants for Pebble (RFI 147 p. 1-2).

These actions do not address the concerns about uncertainty associated with the analysis presented in FEIS, which is actually high but not reported or acknowledged. A cornerstone of the scientific process is the recognition of the uncertainties associated with results of an experiment or analysis, particularly when models are used. Uncertainties represent the degree to which results are true or accurate (Loucks and van Beek 2017) and are of two general types. First, model uncertainties arise from the attempt to represent a process for which there is incomplete understanding, and for which outcomes cannot be or are not precisely predicted with mathematical and statistical techniques (Harmel and Smith 2007). Assumptions are made to bridge these gaps in understanding and to allow predictions to be made, particularly for ecological relations (Vicens et al. 1975). The influence of this on the uncertainty of results depends on the importance of the assumption to the model in which it is used – the more critical the assumption the greater potential for uncertainty to have a significant effect on the predictive ability of the model. Second, parameter uncertainty results from measurement errors of the parameters of interest, an incomplete knowledge of parameter values, ranges, physical meaning, and temporal and spatial variability (Harmel and Smith 2007). Understanding of the uncertainty associated with an analysis or study is critical for decision and policy makers to be aware of and consider when deciding on a course of action; ignoring them could lead to incorrect conclusions and to unanticipated consequence of proposed actions (Loucks and van Beek 2017). It is acknowledged in RFI 167 that “All models, including PHABSIM and HABSYN, have limitations and uncertainties, but they are a valuable tool for providing comparable predictions that can be used to inform decisions.” Additionally, the FEIS acknowledges “There is uncertainty associated with the magnitude of the impact of the mine on streamflow in the NFK, SFK, and UTC.” (Appendix K4.16 -25). These clearly imply that there is, therefore, some level of uncertainty associated with their analysis. However, the applicant completely fails to present or consider these in the FEIS other than a cursory recognition of uncertainties associated with the flow assessments in Appendix 4.16.

Sources of Uncertainty

Within PHABSIM as a modeling framework

All models have uncertainties in both their variables and their relationships (Fischhoff and Davis 2014). Railsback (2016) identified several concerns about the validity of results from using PHABSIM and concluded that it “no longer conforms to standard practices in the wider fields of ecological and wildlife monitoring, especially by using inappropriate spatial scales and out dated methods for modeling habitat preferences and by producing results that lack clear meaning” (p. 721). Nestler et al. (2019) noted that relatively little advancements in the development and use of HSC occurred after 1985 (p. 17) and few, if any, of the issues and uncertainties raised by reviewers and practitioners, were ever addressed in the FEIS. Kondolf (2009) further noted that the WUA as its output of PHABSIM has no clear meaning ecologically, cannot be tested against field observations, and its applicability to management decisions is unclear. Mather et al. (1985) noted the shape of the curve is highly dependent on the site, stream, and time of collection. Similar WUA values from different combinations of flow, substrate, and depth so similar values WUAs should not be interpreted as being equal to another of similar

value in biological or habitat terms unless they are shown to be exact replicas (Mather et al. 1985). This was never considered in the FEIS. Also, the shape of the curve is dependent on the observation of fish numbers, which can vary widely in time in Bristol Bay (Brennan et al. 2019).

Responses to Railsback (2016) by Beecher (2017) and Stalnaker et al. (2017) generally agreed that PHABSIM had important shortcomings and that these should, and could, be addressed and that PHABSIM should be modified rather than being abandoned as suggested by Railsback (2016). Railsback (2017), in response to comments from Beecher (2017) and Stalnaker (2017) on his 2016 publication, noted that the flaws of PHABSIM identified in 2016 were “sufficient to be challenged in court with potentially disastrous consequences” (p. 1).

Reiser and Hilgert (2018) (provided in RFI 167), Pebble consultants, said that many of the improvements suggested but Stalnaker et al. (2017) and Beecher (2017) should be incorporated into PHABSIN to address its limitations. Specifically, Reiser and Hilgert (2018) noted that some of the problems of PHABSIM are now being addressed via incorporation of uncertainty into model structures (P. 281-2). This is commendable and would greatly improve the validity of results from PHABSIM presented in the FEIS and provide valuable insights for decision makers. However, this has been totally ignored in the application of PHABSIM analysis for the proposed Pebble Mine. Castleberry et al. (1996) stated that estimates of WUA should be reported with standard errors or confidence intervals so that decision-makers are informed of the uncertainty associated with the estimates. The failure to consider uncertainty in changes to fish habitats contrasts with many other areas of ecological research that clearly recognize the importance of and need to accurately account for sources of variability when modelling ecological phenomena and making forecasts (Lek 2007). As a consequence, model results about the effect of changes in flow on available fish habitat in FEIS are presented with a false sense of precision that masks their limitations and validity.

The measurement of water velocity was done with a variety of instruments. RFI 147 (p. 9) states “[a]t all 143 transects, hydraulic flow data (e.g., water depth and mean column velocity) were collected at set intervals across each transect under different flow conditions using various meters and profilers including Pygmy, Price AA, Marsh McBirney, and Swoffer current meters (2004-2008), and acoustic Doppler current profilers (2018).” The measurements for each sampling period were checked and verified. However, each instrument measures velocity in a different way and to varying degrees of precision. It is critical to account for this variation in when combining the estimates. The failure to take this step introduces questions about the validity of the estimates of flow velocity used in the analysis.

Uncertainties of HSCs can heavily influence the results of habitat analyses (Ayllon, et al. 2012). Uncertainty arises when models omit variables or relationships, whether because they seem unimportant or because the model does not accommodate them (Fischhoff and Davis 2014). Hydraulic conditions such as flow are necessary but not sufficient to understand biological responses to changes in flow (Stalnaker et al. 2017). PHABSIM is limited in its ability to predict the ecological effects of flow alterations (Kondolf et al. 2000, Railsback 2016) because the habitat selection model in PHABSIM, at least as used in this instance, only considered velocity, depth, and substrate. Habitat use by fish is influenced by a suite of factors and not just those considered in PHABSIM. Habitat use of Brown trout (*Salmo trutta*) (Hayes et al. 2016) and juvenile Coho salmon (*Oncorhynchus kisutch*) (Rosenfeld et al. 2005, Rosenfeld and Ptolemy 2012) were more strongly influenced by food availability than flow and, as result, the shape of habitat suitability curves was very sensitive to food availability and not solely flow. Rosenfeld et al. (2005) noted because the shapes of habitat suitability curves were sensitive to

food abundance that differences in food availability may affect transferability of habitat suitability curves between streams of different productivity. Additionally, factors such as water temperature (Stalnaker et al. 2017) and social status of an individual fish (Rosenfeld et al 2005) influence habitat use.

The validity of habitat suitability curves is also affected by small scale variations in velocity used by drift-feeding fish. Positions fish use have very fine delineations of velocities and the actual area use is within a range that is often very different than the mean velocity of the site. This can lead to large biases in flow assessments because PHABSIM uses mean velocities (Namen et al. 2020). Reiser and Hilgert (2018) noted that the state of Washington requires consideration of factors other than flow that influence habitat suitability. The failure to consider the aggregate of factors influencing the quality and quantity of fish and fish numbers in flow alteration-ecological relations results in continued uncertainty about the scientific validity of conclusions drawn from the use of PHABSIM and other models (Poff et al. 2010). EPA recommended alternatives to PHABSIM (matrix models such as <https://pubs.usgs.gov/of/2018/1056/ofr20181056.pdf>, https://swfsc.noaa.gov/uploadedFiles/Event/s/Meetings/Fish_2015/Document/10.1_Zabel_et_al_2013.pdf, etc.; individual-based models such as hexsim https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHEERL&dirEntryId=338421; mechanistic viable population models such as EDT: https://www.nwcouncil.org/sites/default/files/Vol._VI_Ch._6_EDT_Application.pdf) and suggested use of them to corroborate the PHABSIM results and decrease uncertainty associated with the current analysis. There was no apparent attempt to use EPA's suggestion. Nestler et al. (2019) also identify suitable alternatives.

Consideration of the range of requirements for a given life-history stage of an organism is critical to understanding the effects of environmental alterations (Marra et al. 2015). The PHABSIM analysis focuses on a specific need of a life-history stage rather than the suite of needs required to successfully survive or reproduce at the stage of interest. R2, Pebble consultants, looked at adult spawning, migration and rearing, juvenile rearing and migration, and fry emergence but only used adult spawning and juvenile rearing as their priority life-stages when assessing flow alterations. This oversimplification not only limits the complexity of life history considered in PHABSIM, but also does not fully address the dynamic needs of the fish for those stages.

For example, effects on spawning only consider potential impacts to the actual spawning habitat at the time of spawning. Adults require habitat for holding prior to spawning and to escape predators while spawning to spawn successfully (Quinn 2018). These are generally pools and deeper parts of the channel that are in close proximity to the spawning location. Reduction of flows would likely decrease the availability of these critical habitats and, thus, reduce spawning success, even if the availability of the actual spawning habitat remains unchanged. Additionally, lower flows during spawning results in fish selecting and using areas closer to thalweg, the transect along the deepest part of the channel (May et al. 2009). Because during high flows the thalweg tends to have higher velocities than areas outside of it, redds located near it have a higher probability of being scoured (modified or destroyed from the movement of gravel by the flow) than those closer to the stream margins.

Similarly, the effects of reduced flows on PHABSIM on juvenile fish are limited to a narrow portion of the day when fish are presumably feeding. Fish use completely different habitat at night – generally in areas of slow velocity on the margins of streams (Reeves et al.

2010). Lower flows would likely reduce the availability of these essential habitats. The limited focus of the PHABSIM analysis does not consider the full range of potential impacts of flow alterations on a given life-history stage, which creates a large amount of uncertainty about the conclusion that there will be no effect on fish habitat from flow alterations.

Another source of uncertainty surrounding the use of PHABSIM is its limited ability to accurately predict biological responses to changes in stream flow. Empirical assessments of predictions of habitat use by PHABSIM have been mixed at best. Shirvell (1989) found 70% of the spawning area for Chinook salmon (*O. tshawytscha*) on the Nechako River, British Columbia that was predicted to be unusable by PHABSIM was actually used. Eighty-seven percent of the area predicted to be useable was never used in the three time periods of the study. While Gallagher and Gard (1999) found that the predicted WUA from PHABSIM was significantly correlated with the density of spawning Chinook Salmon in the Merced River, California. They placed transects only at sites of known spawning rather than in a statistically valid manner as is required for PHABSIM results to be unbiased (Williams 2010). A comparison of velocities at which Atlantic salmon (*Salmo salar*) spawned in an English river with those predicted by PHABSIM found that PHABSIM suggested a higher optimum flow than fish were actually observed to use (Gibbins et al. 2002). In a study of juvenile Coho salmon in Washington, Beecher et al. (2010) showed that PHABSIM suggested that the amount WUA decreased with increasing summer flows. However, smolt production actually increased with increasing summer flows. The inconsistency of PHABSIM to properly identify the appropriate relation between WUA and fish density and production demands that predictions from it be viewed with caution at best and that there is likely a large degree of uncertainty associated with them (Kemp and Katopodis 2017).

Within PHABSIM as used for the proposed Pebble Mine

The manner in which habitat preference curves were used in the PHABSIM model is another source of uncertainty in the FEIS. The use curves were developed by combining observations of fish in the affected streams and generic curves used in PHABSIM. Fish observation were made over a series of years (2005 -2008) by two different companies (HDR, Inc. 2005-2007 and R2 Resource Consultants 2008). There was no mention of any attempt to verify the accuracy of the observations or to ensure the compatibility of the observations by the different entities. Variation in condition and among people making observations of fish can be high in many instances (Hagen and Baxter 2005), which would lead to uncertainties with the data. And, there was no apparent attempt to verify the applicability of the generic curves to the affected streams. A recent study (Campbell et al. 2020) attempted to predict growth of juvenile Coho salmon on the Copper River Delta, Alaska with a generic model, the Wisconsin Bioenergetic Model (Kitchell et al. 1974), to determine growth in streams with different thermal regimes. The model was expected to show that fish in the stream near the “optimal” temperature for growth grew more quickly than those in a much cooler stream. The fish, based on actual measures, grew at the same rate. Thus, the application of generic models to specific locations may be limited, and the results likely have a large level of uncertainty unless they are verified.

Failure to Consider the Full Effects to Off-Channel Habitats

The FEIS does not determine the effect of the potential impacts of flow reductions from the proposed mine on off-channel habitat. As an example, for the North Fork of the Koktuli River it states on p. 3.24 – 17: “Streamflows connecting the mainstem channel with OCHs were

hydraulically assessed at multiple locations, and showed connections over a wide variety of flows, ranging from 14 cubic feet per second (cfs) to 490 cfs (R2 et al. 2011a, Appendix 15.1D)]. Approximately 50 percent of OCH area is present with mainstem flows of 20 cfs to 110 cfs, depending on study site. Near-maximum OCH area is estimated to occur in NFK study sites at flows of approximately 100 cfs to 275 cfs.” In the PFEIS it was acknowledged that “Streamflow modeling described in Section 4.16, Surface Water Hydrology (AECOM 2019b), indicates that mean monthly flows during mine operations would maintain stream and OCH connectivity within this range of flows. In general, a majority of OCH appears to become hydraulically connected to the main channel when flows exceed approximately 20 percent of bankfull in all three analysis area rivers. From a flow frequency/duration perspective, the 20 percent of bankfull level equates to roughly the mean July flow at the US Geological Survey gages on each of the three rivers (PLP 2018b). Modeled flows post-closure indicate that during dry years, mainstem connectivity may be less than 14 cfs in late winter during the month of April, but return to connectivity with the mainstem in May.” However, off-channel habitats are never considered in 4.24 of the FEIS, the effects analysis. An examination of projected flows (RFI 019 p. 9), shows that mean flows in the North Fork Kookstul River in April would likely near or below the levels needed to maintain 50% of the area of the off-channel habitat, when Chinook, Coho, and Sockeye salmon fry emerge (3.24 Table 3.24-5). These areas are habitats are critical to the growth and survival of salmonids fry (Moore and Gregory 1988); a reduction in their availability could affect the productivity of affected fish populations.

Off-channel habitats are ecologically significant portions of the stream network and critical for sustaining the productivity of salmon and many other native fish populations (Huntsman and Falke 2019). Off-channel habitats are generally much more productive for juvenile salmonids than those in the main channel (Bellmore et al. 2013). Eighty percent of the number of juvenile Coho salmon were found in off-channel habitats during wet years in Bear Creek, in the Wood River in Bristol Bay (Armstrong and Schindler 2013). During low flow years, access to off-channel areas was limited and densities were higher in the main channel. Juvenile Chinook salmon were also more abundant in off-channel areas compared to the mainstem of the Cheena River, Alaska. The condition of juvenile Coho salmon in the Kwethluk River, Alaska (Malison et al. 2016) and Chinook salmon in the Sacramento River, California (Limm and Marchetti 2009), a measure of habitat productivity (Riberio et al. 2004), was higher in off-channel habitats than in the main channel. The failure to adequately consider how flow alteration affects access to the exclude habitats likely vastly underestimates the effect of flow alterations on fish in the rivers impacted by the mine.

Flow models

Similar to the PHABSIM analysis, estimates of stream flow used in the assessment are presented without any recognition of the uncertainty associated with them. K-P or R2 or BGC Engineering may defend their model here based on the Nash-Sutcliffe efficiency (NSE) coefficient (see RFI 109k). But the NSE only tells part of the story; the measures of absolute and relative error are important to report, and they were not presented. Without that, the flow model may show that the general processes are captured adequately, but that is a different aim than precise prediction. NSE ratings of 75% and better are considered “very good”. NSE from 0.50-0.65 are considered “satisfactory” RFI 109k). NFK 119B had NSE = 0.6 for the calibration period and 0.63 for the prediction period. SFK 100F had NSE = 0.83 and 0.86 for the calibration and validation periods, respectively. (Most of the reaches had NSE between 0.75 and 0.91.) Even

if the NSE ranks as “very good”, there are still significant errors and inability to have precise predictions. As noted by BGC Engineering, “The greatest discrepancy between the modeled and measured flow in the calibration plots... is at the low end of the flow distribution curve” (KP, October 2019 Pebble Project Baseline Watershed Model Update, p. 21).

Furthermore, the baseline watershed model’s calibration period was from October 2005-March 2010 and the validation period was from October 2011-September 2013. The time period from 2005-2013 shows some of the lowest and least variable flows from the period from 1942-2017. (See Fig. 2a from Lubetkin and Reeves for a graph of NFK-A flows.) If the “very good” (as assessed by the NSE measure) baseline watershed model still has errors of this magnitude when used on a relatively constrained data set, it is hard to believe that predictions from it would have much accuracy or precision when applied to data outside the scope of what it was built and tested on.

Interpolation of Weighted Useable Area (WUA) to Areas Between measured Transects

The estimates of the amount of WUA used in the effects analysis were done by presuming a relation between the bankfull width of particular habitat type, the relative distance of the habitat unit from the two nearest reference points (transects) and the calculated WUAs at the respective reference points. This is represented in the Equations 1 and 2 (from review of Lubetkin and Reeves).

$$WUA_{syn,i} = \frac{\frac{WUA_{A,sim,i}}{d_A} + \frac{WUA_{B,sim,i}}{d_B}}{\frac{1}{d_A} + \frac{1}{d_B}} \quad \text{Eq. 1}$$

Where:

$WUA_{syn,i}$ = the synthesized WUA curve at flow i at the habitat unit where $i = 1 \dots 30$ flows creating the Q-WUA curve;

$WUA_{A,sim,i}$ = the simulated WUA at Transect A at flow i ;

$WUA_{B,sim,i}$ = the simulated WUA at Transect B at flow i ;

d_A = the distance from the center of the habitat unit to Transect A; and

d_B = the distance from the center of the habitat unit to Transect B.

$WUA_{A,sim,i}$ and $WUA_{B,sim,i}$ are adjustments to the PHABSIM values that are designed to account for the potential differences in the bankfull widths of the stream at Transects A, B, and the habitat unit. Specifically,

$$WUA_{A,sim,i} = WUA_{A,i} \times \frac{w_{meso}}{w_A} \quad \text{Eq. 2}$$

There are two assumptions required in interpolating the amount of WUA between the reference points. The first is that the change in depth and substrate, two components of WUA, between two transects occurs uniformly such that the closer the point of interest is to one transect the more similar it is to that transect. HABSYN assumes that a habitat unit of interest will have characteristics that are strictly proportional to the corresponding characteristics of its upstream and downstream neighboring habitats units of the same type, even though it is separated from those by habitat units of other types. That is, HABSYN asserts that a riffle could be modeled

based on riffles up- and downstream of it, even if there are intervening island channels, pools, and/or run habitat units. This fails to account for the fact that some sections of the reach may be gaining or losing depending on the groundwater dynamics and that in practice the particular features of the streambed, such as a substrate composition, do not exhibit gradual changes but are very variable and heterogeneous, particularly in pool-riffle reaches (Buffington and Montgomery 1999) like those found in the affected streams. Payne (2003 cited in Nestler et al. 2019) noted that that physical conditions present at any given point actually do not extend very far from that point (Payne, 2003 cited in Nestler et al. 2019). Single dimensional models such as PHABSIM are limited in the ability to account for this variability (Parasiewicz and Dunbar 2001, Parasiewicz 1996).

A second assumption was that the relation between WUA and bankfull width (Equation 2) was linear. This suggest that the amount of WUA was directly related to bankfull width and that velocity, substrate, and depth changed directly with bankfull width. This is very questionable. A point that is narrower than the reference (ie. has smaller bankfull width) but receives the same flow would not necessarily have a proportionally smaller WUA. Velocities would be expected to be higher in a smaller channel, depth increase, and the substrate profiles tend towards larger sizes. All of these would affect the estimated WUA.

Equation 2 also presumes that the streambed configuration of a particular habitat unit is the same between the point of interest and the transects being used. Two different channel configurations (Fig. 1). can have the same bankfull width but very different WUAs because of differences in velocities and substrate composition. These assumptions, and others (See review by Lubetkin and Reeves) are critical to the validity of the estimates of WUA but none were acknowledged in the analysis or their potential impacts on uncertainty considered in the effects analysis.

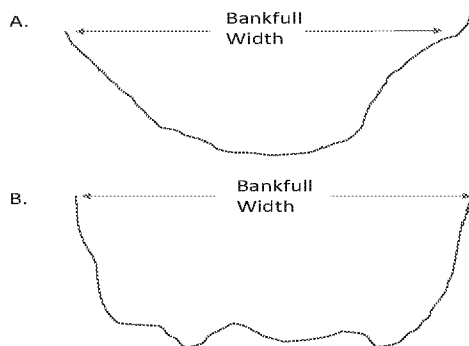


Figure 1. Examples of channels with the same bankfull width and different channel configurations.

Failure to Consider Climate Change

Knight Piésold (2018) suggested that the change in flows [added: in the area of the mine] is most likely attributed to “strong atmospheric and oceanic climate forcings [the Pacific Decadal Oscillation (PDO)] rather than climate change, as it is commonly defined.” (p. 106). They further suggest that it should be expected the observed changes in flow will be reversed when the PDO shifts back to cold phase. However, stream flows in Alaska are affected by two independent processes, climate change and the Pacific Decadal Oscillation (PDO), that can work in concert or

in opposition, depending on the phase and strength of the PDO. Knight Piésold (2018) recognized that streamflow patterns in the recent past and regional annual hydrograph shapes are changing, with increasing winter flows and decreasing summer flows (p. 107). This is consistent with the projections of future flows resulting from climate change (Wobus et al. 2015). The FEIS (K4.16 -25) notes that there is uncertainty regarding future rainfalls and temperatures as a result of climate change but this issue is does not appear to be considered elsewhere in the document.

The scientific literature on climate change and the PDO does not support this contention. There is uncertainty about the characteristics of future PDOs and how they will affect future climatic conditions. Furtado et al. (2011) suggested that the PDO does not exhibit significant changes in the spatial or temporal characteristics under a warming climate. The amplitude and time scale of PDO changes are projected to decrease in other analyses (Zhang and Delworth 2016, Perlwitz et al. 2017, Geng et al. 2019). Deser et al. (2016) estimated that the PDO could offset the effects of climate change 10 – 30%, which suggests that the signal of climate change in the Pebble Mine area is still likely to be significant and should be considered in the effects analysis. Both processes should be explicitly considered, especially since the any changes in flow due to the proposed mine would be permanent.

The validity of the flow analysis is further compromised by the use of long-term flow average (1942 – 2017) rather than using the period of 1977 – 2017 as the baseline for representing future climate conditions. Knight Piésold (2018) recommended that “if a downward step in temperatures is not anticipated and the post 1976 dataset is believed to better represent future climate conditions, as much of the literature suggests, then it would be most appropriate to use only the more recent portion of the historical temperature record to simulate probable future temperature conditions” (p. 117). Air temperatures and amount of precipitation Alaska begin to increase around 1977 as result of a shift in the Pacific Decade Oscillation; (Knight Piésold 2018 PLP Hydromet Report). Knight Piésold (2018) noted that “[t]he 1943-2016 precipitation records for Iliamna indicate that annual total precipitation in the Pebble Project area has remained fairly consistent over time, and there is no trend evident in the annual precipitation values over the full period of record. They further state that “[t]here is no statistically significant trend in the 1943-2016 precipitation record. Splitting the winter/spring precipitation dataset according to the timing of the cold and warm phases of the PDO reveals that there is no significant trend during the cold phase, but there is a significant decreasing trend during the warm phase. As such, it is reasonable to conclude that there is more likely to be a decrease in winter/spring precipitation than an increase” (p.117). An examination of Figure 2 shows that during the period of 1942 – 1976 (pre-PDO change) flows in the North Fork of the Koktuli River were below the long-term average in 16 of the 34 years (47.1%). In contrast, 67.6% (23/39) were below average following the PDO shift (1977 – 2017). Use of the long-term average results in a higher average flow in the assessment than what has occurred more recently in the streams affected by the mine.

Future flows in the streams affected by the mine are projected to change as a result of changes in air temperatures and the form and timing of precipitation (Wobus et al. 2015). Summer flows are projected be 10 – 15% below a baseline of 1980 – 2009. and the use of the long-term average likely underestimates the effects of reductions in flow from the mine. Flows at other times of the year are also likely to change also. Peak flows in May and June, which aide the seaward movement of smolts, are likely to be reduced because a reduction in the snow pack

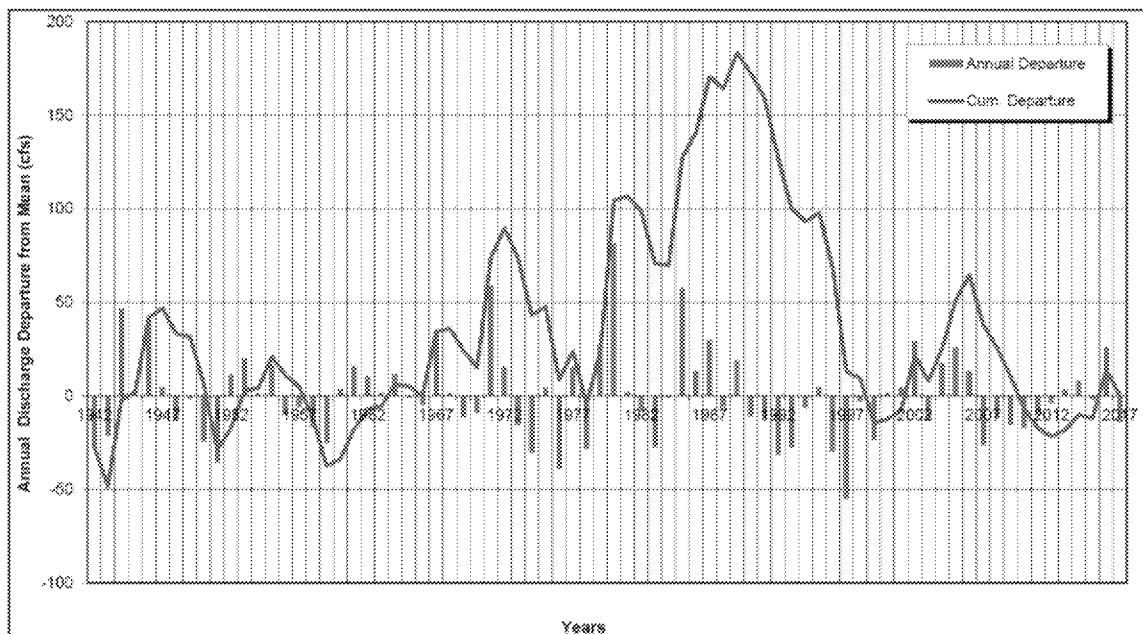


Figure 2. Yearly departure of stream flows from the long-term average flow (1942 – 2017) in the North Fork of the Koktuli River, AK (Fig. 8.6 from: Knight Piésold 2018 PLP Hydromet Report p. 95).

that results from warmer winter air temperatures and precipitation falling as rain instead of snow.

This is the time when water withdrawals for mine operation will be the largest (North Fork Koktuli River 67.8 and 90.6 cfs) or among the largest (South Fork Koktuli River 13.2 and 19.0 cfs and Upper Talerik Creek 0.9 and 1.9 cfs) (Table 9 RFI048 p. 31) even with the addition of returned treated water. Given that future summer flows are likely to be lower than present flows, the analysis in the FEIS likely vastly underestimates that effect of water withdrawals for mining operation and closure on fish.

Use of Multiple Models

The analysis of the potential impacts of flow alterations involves the use of several models (Fig. 3). The flow models generate estimates of pre-mine, during operations, and post-closure flows that are used in the habitat model, HABSYN with the WUA-flow relationships modeled in PHABSIM. The FEIS acknowledges that “There is uncertainty associated with the magnitude of the impact of the mine on streamflow in the NFK, SFK, and UTC.” (Appendix K4.16 -25), which imparts uncertainty to the PHABSIM analyses.

Additionally, Wobus and Lubetkin and Reeves (Reports on FEIS) identified several issues concerning the flow models, suggesting that they have a high degree of uncertainty. The uncertainties of PHABSIM model and output, of which there are several, are discussed in this review and in more detail by Lubetkin and Reeves. Because HABSYN is a proprietary model, it is not possible to ascertain the uncertainties associated with it. However, given that all models have uncertainties in both their variables and their relationships (Fischhoff and Davis 2014), it is prudent to assume that HABSYN has uncertainties associated with its results. Uncertainties are

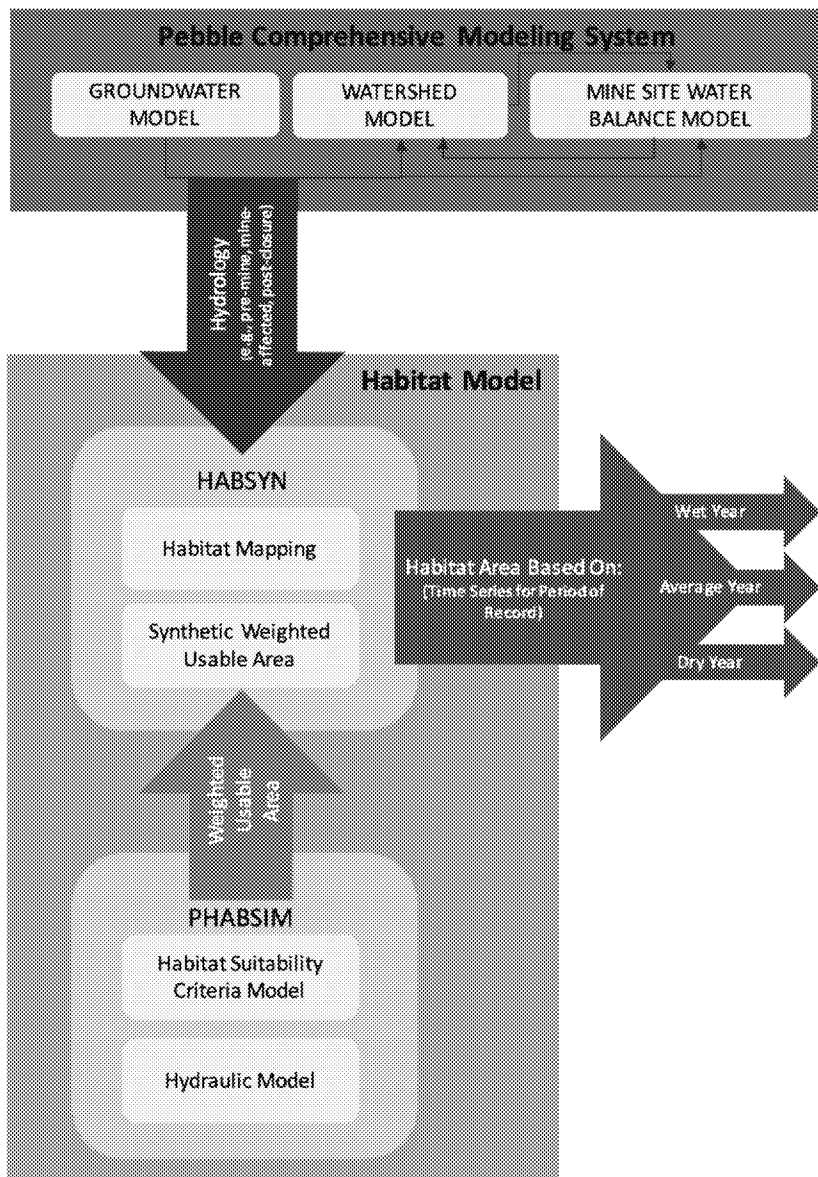


Figure 7-1. Schematic showing the integration of the Pebble Comprehensive Modeling System and the Habitat Model that were used together to estimate available fish habitat.

Figure 3. Diagram of models used to assess impacts of flow alteration on the quantify of fish habitat. (from: RFI 147)

not reduced or cancelled when results for one model are used as input for another model, as suggested in the FEIS (Appendix K4.16 – 25). Rather, they are compounded or magnified, which results in greater levels of uncertainties as more models are used (Figure 4).

Knowing the precision of a model result is arguably as important as having the result itself. The combined use of the six models (hydraulic model, habitat suitability criteria model, PHABSIM, groundwater model, watershed model, and mine site water balance model) that feed into HABSYN without considering the uncertainty associated with them individually or in concert makes it impossible to assess the confidence the reader should have in the HABSYN

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 &\text{PRECISE NUMBER} + \text{PRECISE NUMBER} = \text{SLIGHTLY LESS PRECISE NUMBER} \\
 &\text{PRECISE NUMBER} \times \text{PRECISE NUMBER} = \text{SLIGHTLY LESS PRECISE NUMBER} \\
 &\text{PRECISE NUMBER} + \text{GARBAGE} = \text{GARBAGE} \\
 &\text{PRECISE NUMBER} \times \text{GARBAGE} = \text{GARBAGE} \\
 &\sqrt{\text{GARBAGE}} = \text{LESS BAD GARBAGE} \\
 &(\text{GARBAGE})^2 = \text{WORSE GARBAGE} \\
 &\frac{1}{N} \sum (\text{N PIECES OF STATISTICALLY INDEPENDENT GARBAGE}) = \text{BETTER GARBAGE} \\
 &(\text{PRECISE NUMBER})^{\text{GARBAGE}} = \text{MUCH WORSE GARBAGE} \\
 &\text{GARBAGE} - \text{GARBAGE} = \text{MUCH WORSE GARBAGE} \\
 &\frac{\text{PRECISE NUMBER}}{\text{GARBAGE} - \text{GARBAGE}} = \text{MUCH WORSE GARBAGE, POSSIBLE DIVISION BY ZERO} \\
 &\text{GARBAGE} \times 0 = \text{PRECISE NUMBER}
 \end{aligned}$$

Figure 4. From xkcd.com, April 17, 2020.

results; the standard errors of the WUA predictions from HABSYN were not disclosed if they were assessed at all. Without such a measure, we have no context for how much confidence to have in the presented results or even if the model had the power to detect if changes in flow would affect the quantity of available fish habitat.

Conclusions

Cooperating agencies (EPA, ADFG) and interested parties repeatedly called for the ACOE to divulge the uncertainties of their conclusion that potential impacts on fish habitat from altered flows resulting from the proposed Pebble Mine will be neutral to slightly positive. The Environmental Protection Agency even offered alternative models to those used in the FEIS analysis to improve or verify results because of the recognized short-comings of PHABSIM. The ACOE acknowledged in RFI 167 and the FEIS that the flow models used in the effects analyses have uncertainties. Also, Pebble consultants (R2 in Reiser and Hilgert (2018)) acknowledge that the PHABSIM model used in the analysis has shortcomings and that they could be addressed via incorporation of uncertainty into model structures.

The FEIS explicitly acknowledges that there was uncertainty with the results of the flow analyses used to assess the effects of the mine on fish habitat. Specifically, it states: (1) “There is uncertainty associated with the magnitude of the impact of the mine on streamflow in the NFK, SFK, and UTC.” (Appendix 4.16 -24) and there are “... some apparent anomalies [added: with the flow analyses]—which might be attributable to typographic errors or errors in computations or assumptions.” (Appendix 4.16 -24); and (2) “The EIS team does not understand the inner workings of the model well enough to confirm that the values presented are all correct.” (Appendix 4.16 – 24). It then fails to address or consider them in the FEIS, incorrectly claiming that these errors cancel each other out.

Recognizing and considering uncertainty associated with an analysis or study is critical when deciding on a course of action; ignoring it could lead to incorrect conclusions and unanticipated consequence of proposed actions (Fischhoff and Davis 2014, Loucks and van Beek 2017). The results and conclusions of the analysis of effects of flow alteration on fish habitat in the PFEIS are presented with a false sense of precision and validity. This is totally unwarranted given that there are methods available to address uncertainties associated with PHABSIM (e.g., Williams 1996, 2010) and that the requirement to divulge uncertainties is a clear component of the scientific process. An inappropriate tool will always be a bad tool and increase the probability of poor decision-making (V€or€osmarty et al. 2010). A decision to allow the mine to go forward based on the highly questionable analysis and conclusions in the PFEIS will very likely result in large, irreversible ecological, economic, and social damage to the highly valuable fish resources and communities of Bristol Bay.

Table 1. Summary of source of uncertainty in the analysis of the potential effects of flow alterations resulting from the operation of the Pebble mine on fish habitat.

Source	Level of Uncertainty	Reason
PHABSIM	High	<p>Use of generic habitat use relations</p> <p>Failure to consider all factor influencing habitat use</p> <p>Failure to consider all potential impacts that could results from flow alterations</p> <p>Mixed performance when results of PHABSIM have been validated</p>
HABSYN	High	<p>Underlying assumptions (averaging across up- and downstream habitat units; linear adjustments for bankfull width and flow) do not hold up to scrutiny</p> <p>Data requirements include flow data from river locations as little as 70 feet apart</p> <p>Unclear how the model functions at a daily timestep compared to a monthly one</p> <p>Proprietary model that has not been peer-reviewed or independently validated</p>
Inaccurate assessment of off-channel habitat	Moderate-high	<p>Only considered effect of flow reductions on access to off-channel and not to the reduction in area. This vastly underestimates the consequences of the loss of these areas ecologically important habitats</p>
Flow models	High	<p>Failure to recognize inexact relation between measured and modeled flows</p> <p>See reports by Wobus and by Lubetkin and Reeves</p>
Interpolation of Wetted Useable Area (WUA)	High	<p>Assumptions associated with doing this were not met</p> <p>Also see additional concerns in Lubetkin</p>

Failure to consider climate change	High	Well supported and recognized science is available that suggests that signal of climate change on the area of the mine will be major and that future flows will be very different than that used in the effects analysis
Use of multiple models	High	The analysis uses a large number of models with results of one feeding into another. Uncertainties are compounded not cancelled.

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